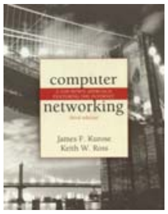
Chapter 1
Introduction



Computer Networking: A Top Down Approach Featuring the Internet, 3rd edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2004.

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Thanks and enjoy! JFK/KWR

Chapter 1: Introduction

Our goal:

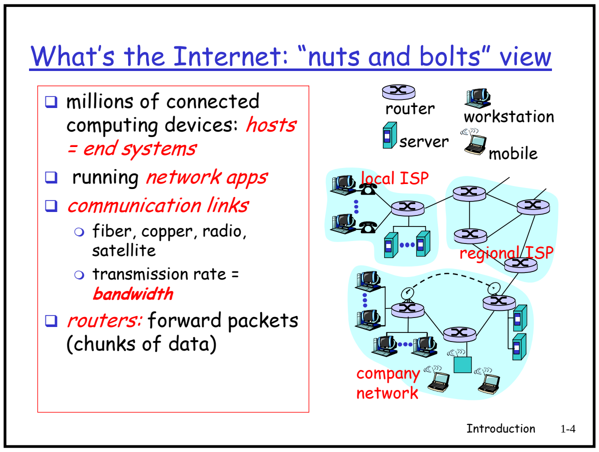
- get "feel" and terminology
- more depth, detail *later* in course
- approach:
  - use Internet as example

Overview:

- what's the Internet
- what's a protocol?
- network edge
- network core
- access net, physical media
- Internet/ISP structure
- performance: loss, delay
- protocol layers, service models
- network modeling

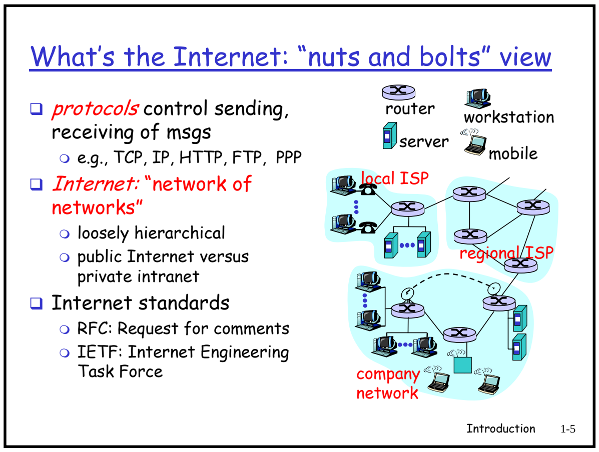
Chapter 1: roadmap

1.1 What *is* the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History



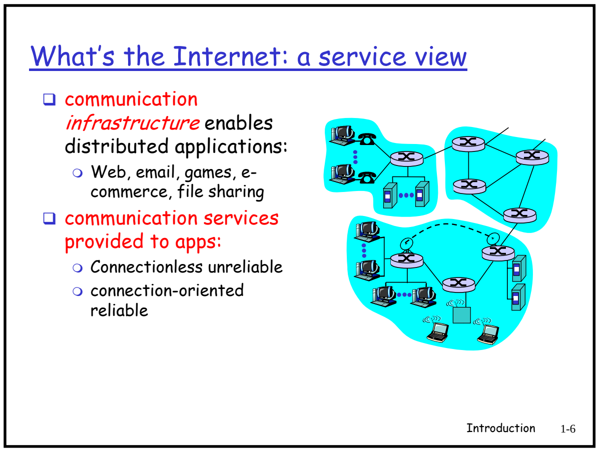
What's the Internet: "nuts and bolts" view

- millions of connected computing devices: *hosts = end systems*
- running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate = ***bandwidth***
- *routers:* forward packets (chunks of data)



What's the Internet: "nuts and bolts" view

- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, FTP, PPP
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: a service view

- communication *infrastructure* enables distributed applications:
  - Web, email, games, e-commerce, file sharing
- communication services provided to apps:
  - Connectionless unreliable
  - connection-oriented reliable

What's a protocol?

human protocols:

- "what's the time?"
- "I have a question"
- introductions

… specific msgs sent

… specific actions taken when msgs received, or other events

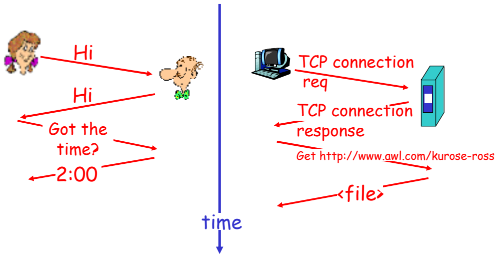
network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

What's a protocol?

a human protocol and a computer network protocol:



Q: Other human protocols?

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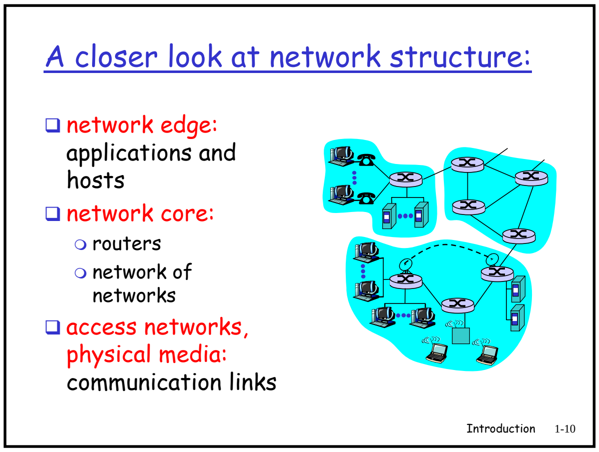
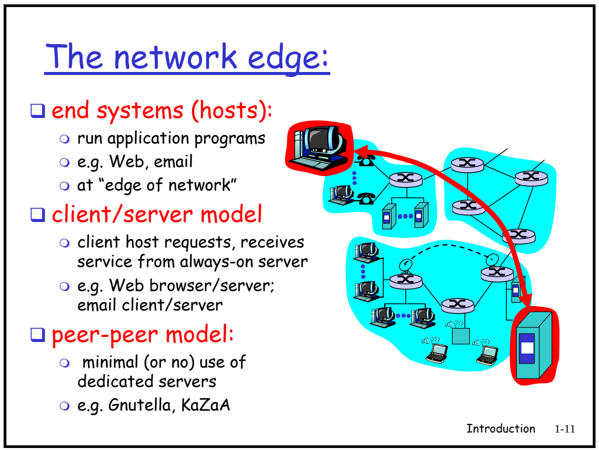


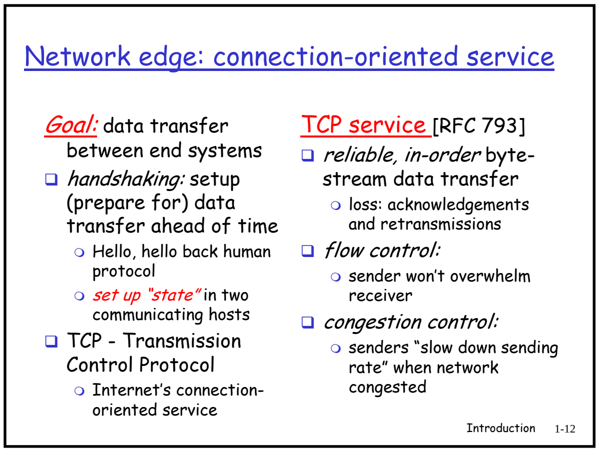
A closer look at network structure:

- network edge: applications and hosts
- network core:
  - routers
  - network of networks
- access networks, physical media: communication links



The network edge:

- end systems (hosts):
  - run application programs
  - e.g. Web, email
  - at “edge of network”
- client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- peer-peer model:
  - minimal (or no) use of dedicated servers
  - e.g. Gnutella, KaZaA



Network edge: connection-oriented service

Goal: data transfer between end systems

- *handshaking:* setup (prepare for) data transfer ahead of time
  - Hello, hello back human protocol
  - *set up “state”* in two communicating hosts
- TCP - Transmission Control Protocol
  - Internet’s connection-oriented service

TCP service [RFC 793]

- *reliable, in-order* byte-stream data transfer
  - loss: acknowledgements and retransmissions
- *flow control:*
  - sender won’t overwhelm receiver
- *congestion control:*
  - senders “slow down sending rate” when network congested

Network edge: connectionless service

Goal: data transfer between end systems
- same as before!

- UDP - User Datagram Protocol [RFC 768]:
  - connectionless
  - unreliable data transfer
  - no flow control
  - no congestion control

App's using TCP:
- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

App's using UDP:
- streaming media, teleconferencing, DNS, Internet telephony

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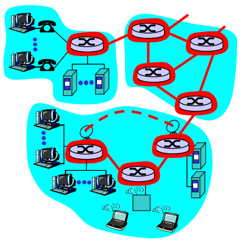
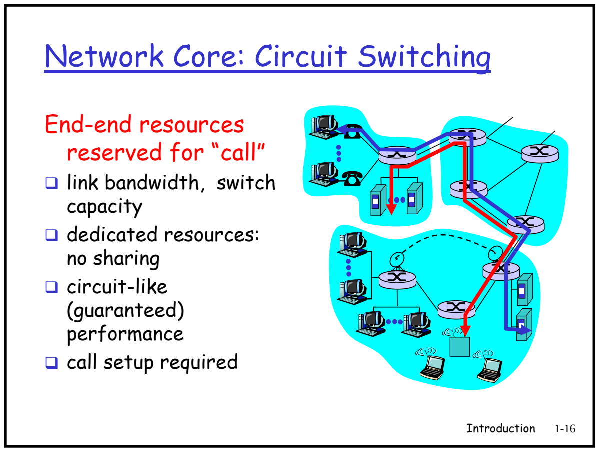
The Network Core

- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"

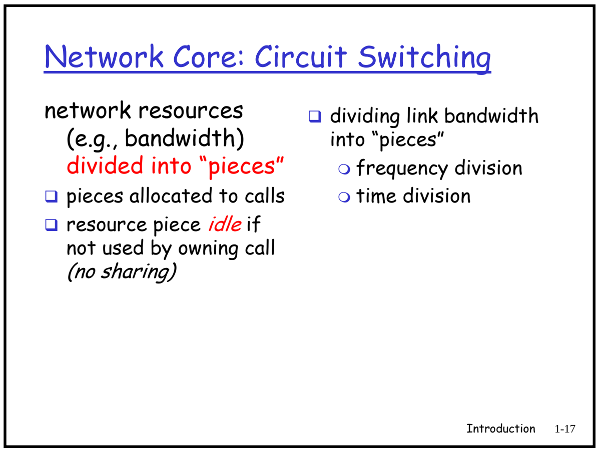




Network Core: Circuit Switching

End-end resources reserved for "call"

- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required

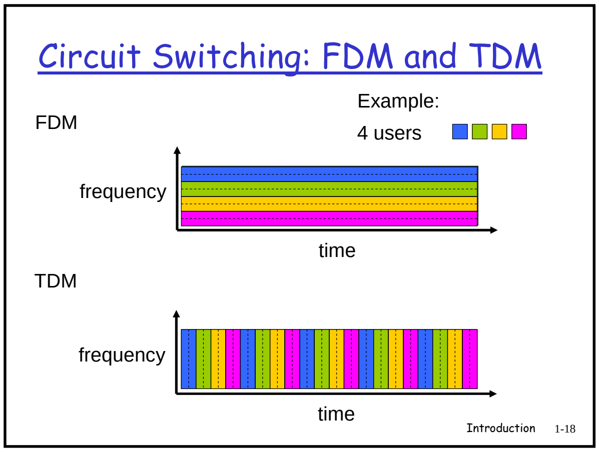


Network Core: Circuit Switching

network resources (e.g., bandwidth) divided into "pieces"

- pieces allocated to calls
- resource piece *idle* if not used by owning call *(no sharing)*

- dividing link bandwidth into "pieces"
  - frequency division
  - time division



Circuit Switching: FDM and TDM

Example:

4 users 🟦🟩🟨🟪

Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots
  - 500 msec to establish end-to-end circuit

Work it out!

Network Core: Packet Switching

each end-end data stream divided into *packets*

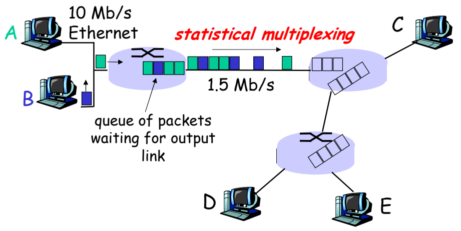
- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*

~~Bandwidth division into "pieces"~~
~~Dedicated allocation~~
~~Resource reservation~~

resource contention:

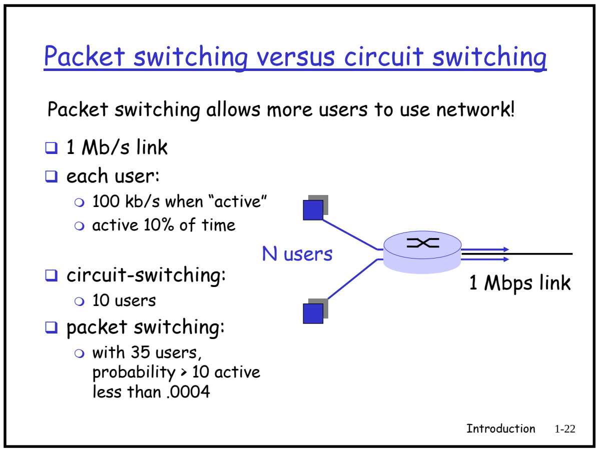
- aggregate resource demand can exceed amount available
- congestion: packets queue, wait for link use
- store and forward: packets move one hop at a time
  - Node receives complete packet before forwarding

Packet Switching: Statistical Multiplexing



Sequence of A & B packets does not have fixed pattern ➔ ***statistical multiplexing***.

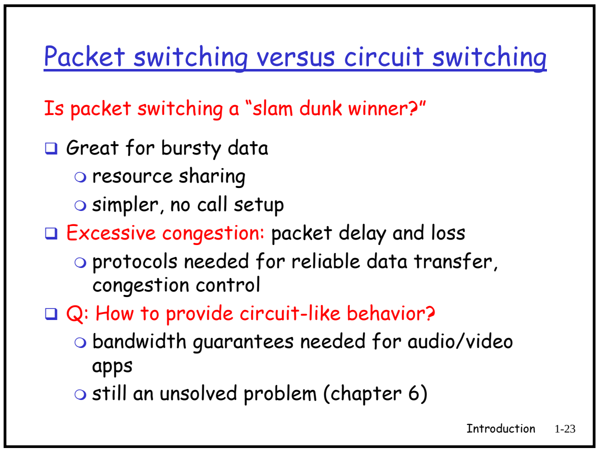
In TDM each host gets same slot in revolving TDM frame.



Packet switching versus circuit switching

Packet switching allows more users to use network!

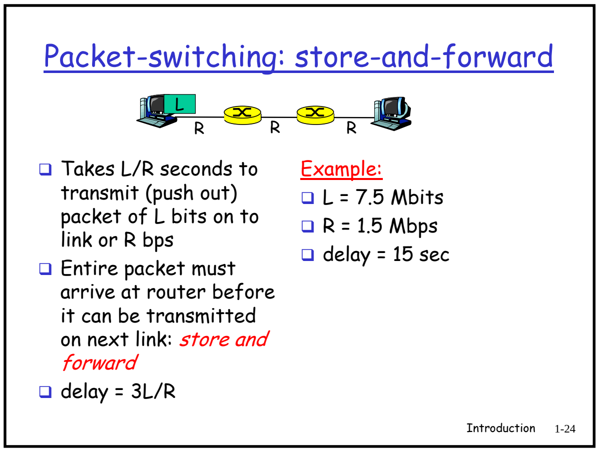
- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time
- circuit-switching:
  - 10 users
- packet switching:
  - with 35 users, probability > 10 active less than .0004



Packet switching versus circuit switching

Is packet switching a "slam dunk winner?"

- Great for bursty data
  - resource sharing
  - simpler, no call setup
- Excessive congestion: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 6)



Packet-switching: store-and-forward

- Takes L/R seconds to transmit (push out) packet of L bits on to link or R bps
- Entire packet must arrive at router before it can be transmitted on next link: *store and forward*
- delay = 3L/R

Example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- delay = 15 sec

Packet-switched networks: forwarding

- *Goal:* move packets through routers from source to destination
  - we'll study several path selection (i.e. routing) algorithms (chapter 4)
- datagram network:
  - *destination address* in packet determines next hop
  - routes may change during session
  - analogy: driving, asking directions
- virtual circuit network:
  - each packet carries tag (virtual circuit ID), tag determines next hop
  - fixed path determined at *call setup time*, remains fixed thru call
  - *routers maintain per-call state*

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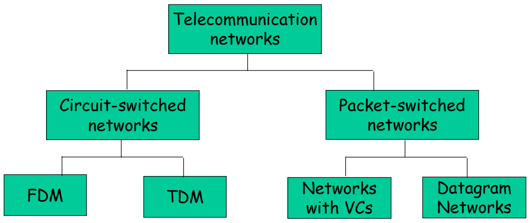
Network Taxonomy



- Datagram network is *not* either connection-oriented or connectionless.
- Internet provides both connection-oriented (TCP) and connectionless services (UDP) to apps.

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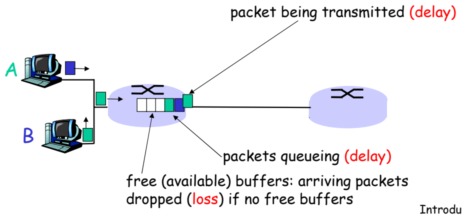
How do loss and delay occur?

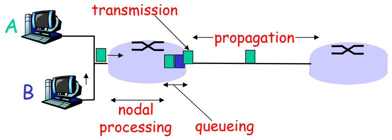
packets *queue* in router buffers

- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn


packet being transmitted (delay)
A
B
packets queueing (delay)
free (available) buffers: arriving packets
dropped (loss) if no free buffers

Four sources of packet delay

- 1. nodal processing:
  - check bit errors
  - determine output link
- 2. queueing
  - time waiting at output link for transmission
  - depends on congestion level of router



Delay in packet-switched networks

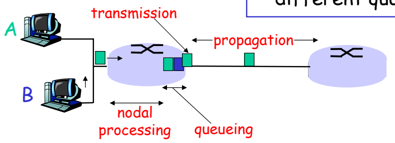
3. Transmission delay:

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

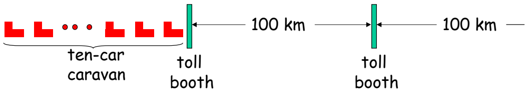
4. Propagation delay:

- d = length of physical link
- s = propagation speed in medium (~2x10^8 m/sec)
- propagation delay = d/s

Note: s and R are *very* different quantities!

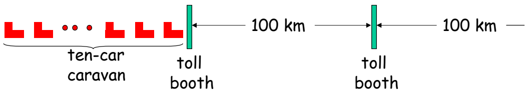


Caravan analogy



- Cars "propagate" at 100 km/hr
- Toll booth takes 12 sec to service a car (transmission time)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?
- Time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
- Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- A: 62 minutes

Caravan analogy (more)



- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?
- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
  - See Ethernet applet at AWL Web site

Nodal delay

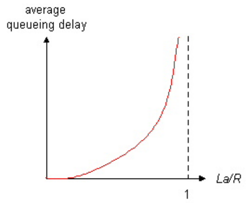
$$\boxed{d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}}$$

- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

Queueing delay (revisited)

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate

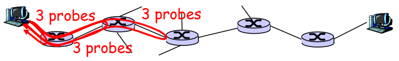
traffic intensity = La/R



- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more “work” arriving than can be serviced, average delay infinite!

“Real” Internet delays and routes

- What do “real” Internet delay & loss look like?
- Traceroute program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i*:
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.



“Real” Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

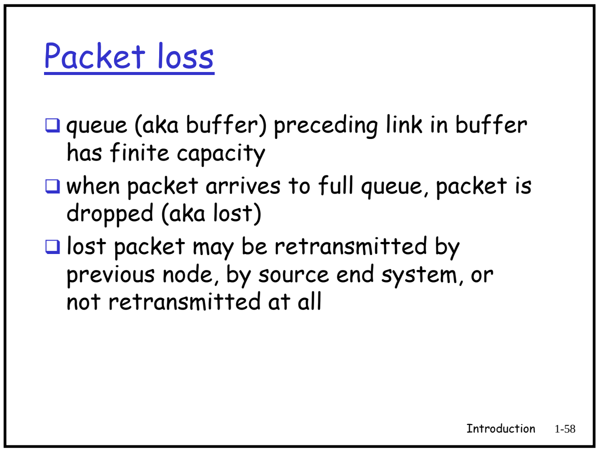
Three delay measements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *

19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

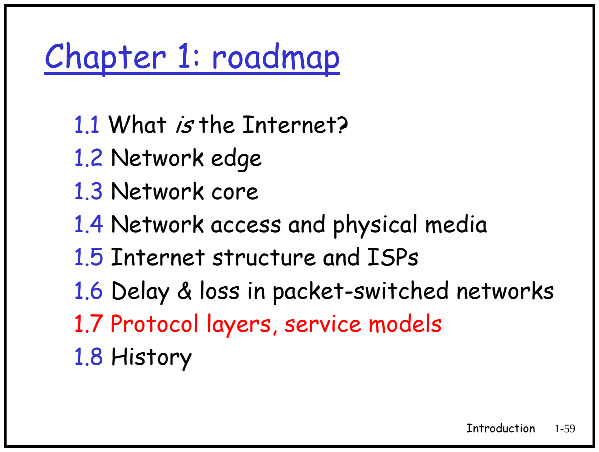
trans-oceanic link

* means no reponse (probe lost, router not replying)



Packet loss

- ❑ queue (aka buffer) preceding link in buffer has finite capacity
- ❑ when packet arrives to full queue, packet is dropped (aka lost)
- ❑ lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all



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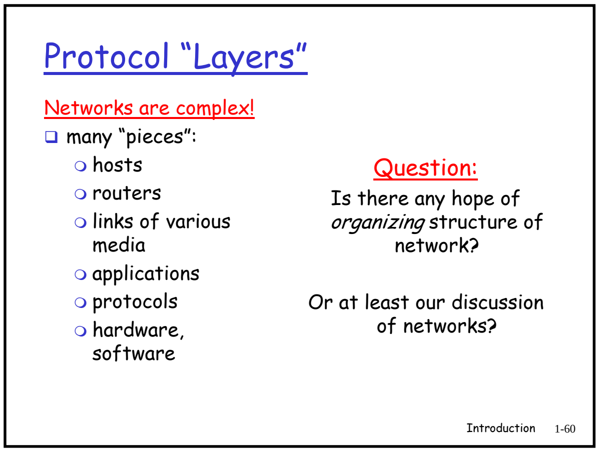


Protocol "Layers"

Networks are complex!

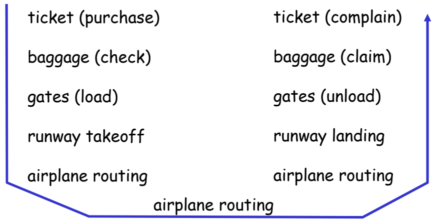
- ❑ many "pieces":
  - ❍ hosts
  - ❍ routers
  - ❍ links of various media
  - ❍ applications
  - ❍ protocols
  - ❍ hardware, software

Question:

Is there any hope of *organizing* structure of network?

Or at least our discussion of networks?

Organization of air travel


ticket (purchase)

baggage (check)

gates (load)

runway takeoff

airplane routing

airplane routing

airplane routing

runway landing

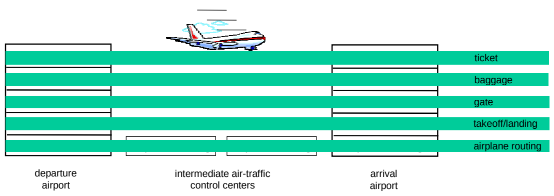
gates (unload)

baggage (claim)

ticket (complain)

- a series of steps

Layering of airline functionality


ticket

baggage

gate

takeoff/landing

airplane routing

departure airport

intermediate air-traffic control centers

arrival airport

Layers: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below

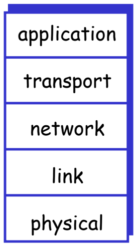
Why layering?

Dealing with complex systems:

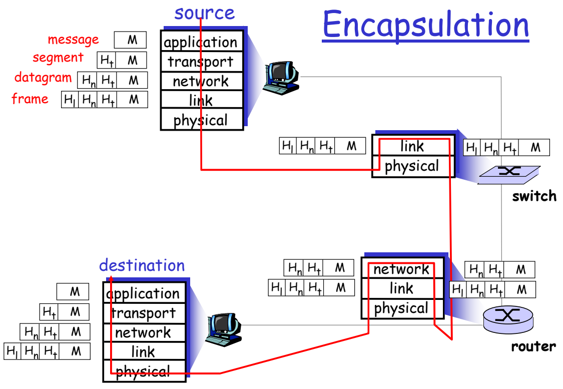
- explicit structure allows identification, relationship of complex system's pieces
  - layered reference model for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system
- layering considered harmful?

Internet protocol stack

- application: supporting network applications
  - FTP, SMTP, STTP
- transport: host-host data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - PPP, Ethernet
- physical: bits "on the wire"



Encapsulation



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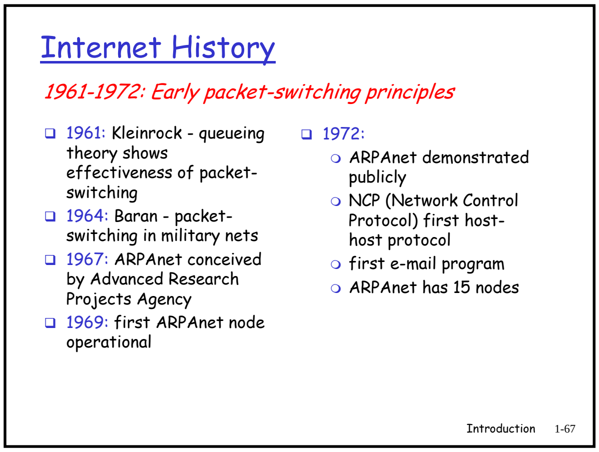

Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

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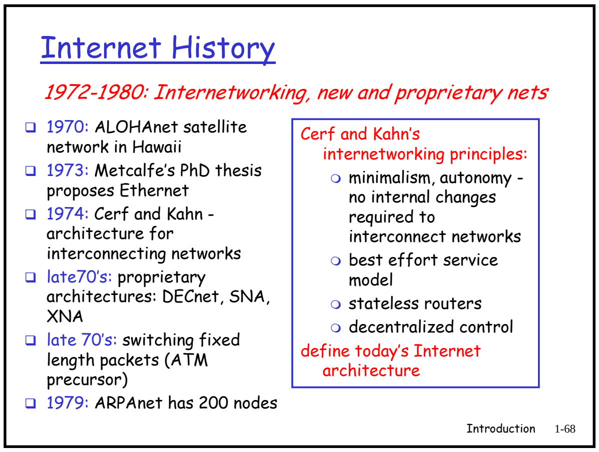

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1973: Metcalfe's PhD thesis proposes Ethernet
- 1974: Cerf and Kahn - architecture for interconnecting networks
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:
- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

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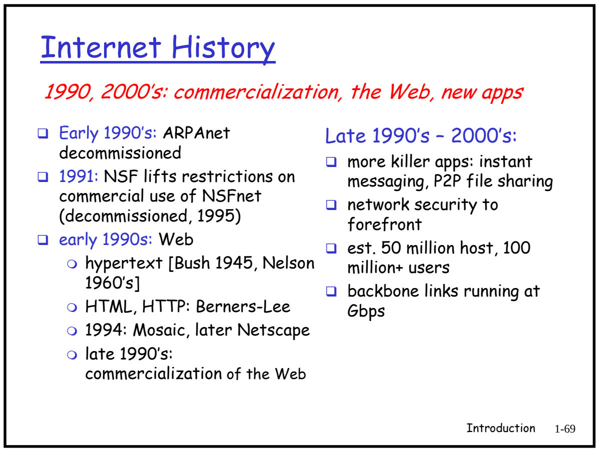

Internet History

1990, 2000's: commercialization, the Web, new apps

- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

Late 1990's – 2000's:
- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

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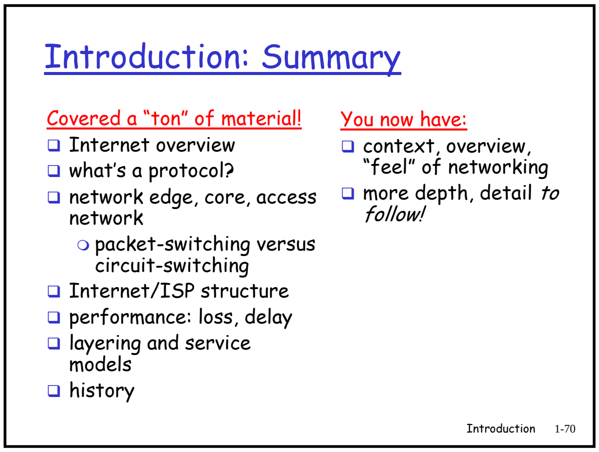

Introduction: Summary

Covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
- Internet/ISP structure
- performance: loss, delay
- layering and service models
- history

You now have:

- context, overview, "feel" of networking
- more depth, detail *to follow!*